National Aeronautics and
Space Administration

CLARREO Pathfinder

Mission Overview and Objectives

Raj Bhatt, Yolanda Shea
and CPF Team
NASA Langley Research Center
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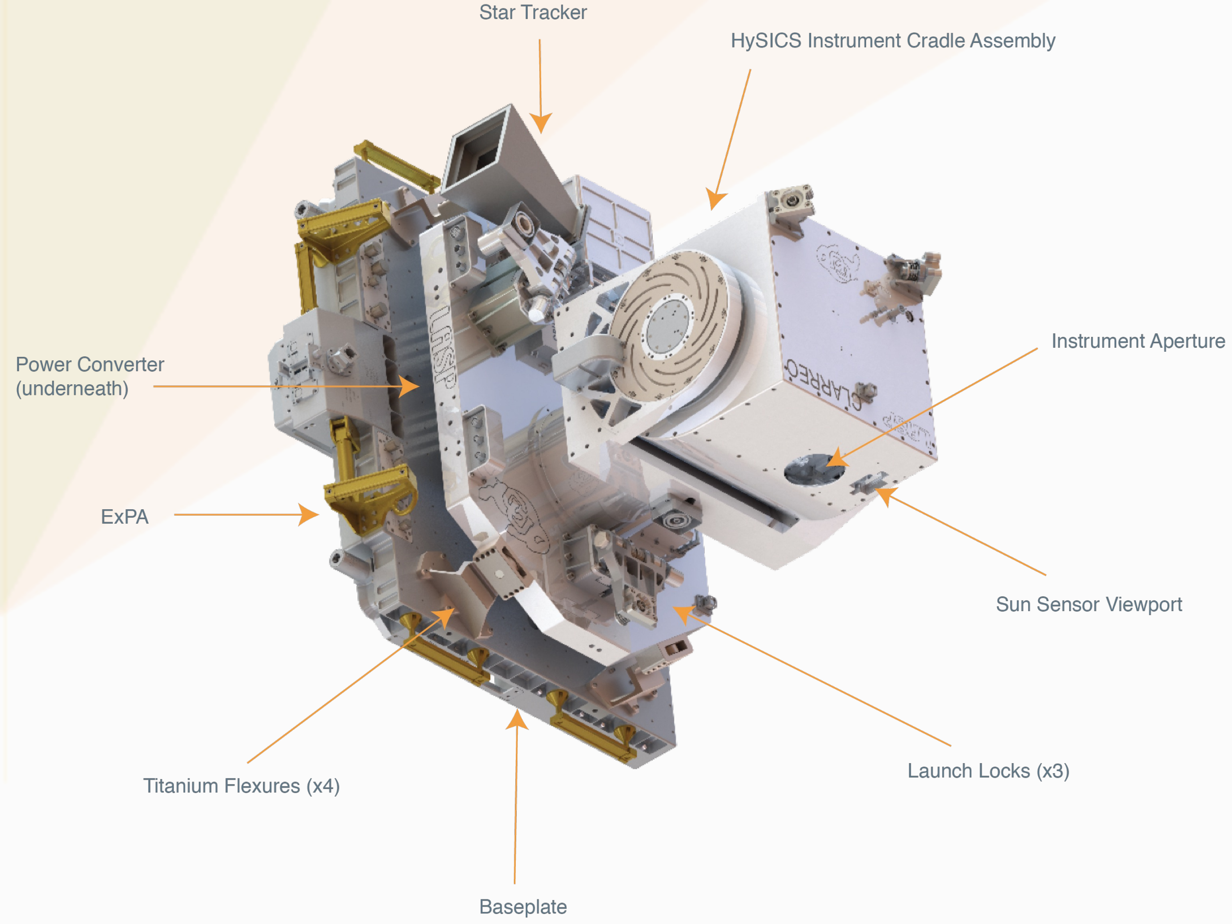
GSICS Data & Research Working Groups
Annual Meeting 2023

CLARREO Pathfinder Payload

HySICS: HyperSpectral Imager for Climate Science



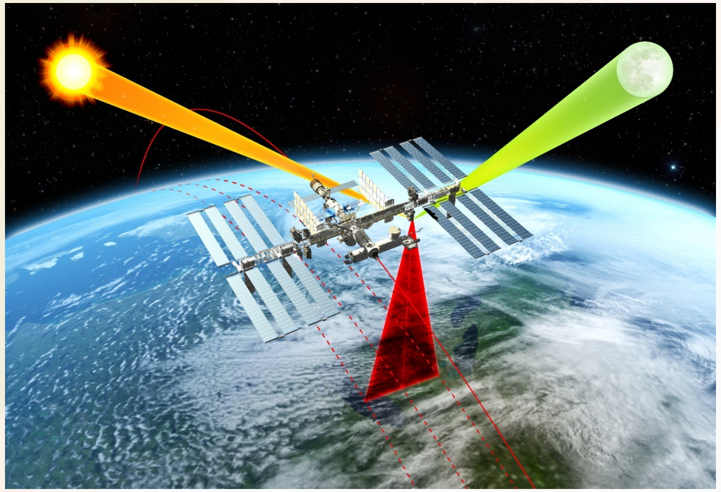
Push-broom spectrometer

Spectral Range	350 nm – 2300 nm
Spectral Sampling	3 nm
Radiometric Uncertainty	0.3% (1-sigma)
Swath Width	10° (70 km nadir)
Spatial Sampling	0.5 km
Platform	ISS

https://clarreo-pathfinder.larc.nasa.gov/

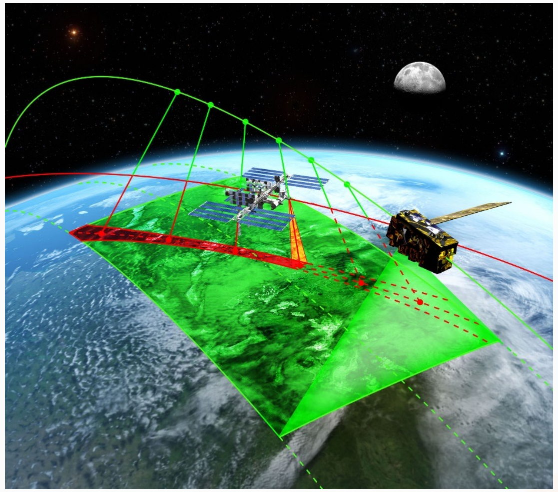
CPF Science Objectives

Objective #1: High Accuracy SI-Traceable Reflectance Measurements



Demonstrate on-orbit calibration ability to reduce reflectance uncertainty by a factor of ***5-10 times*** compared to the best operational sensors on orbit.

Objective #2: Inter-Calibration Capabilities



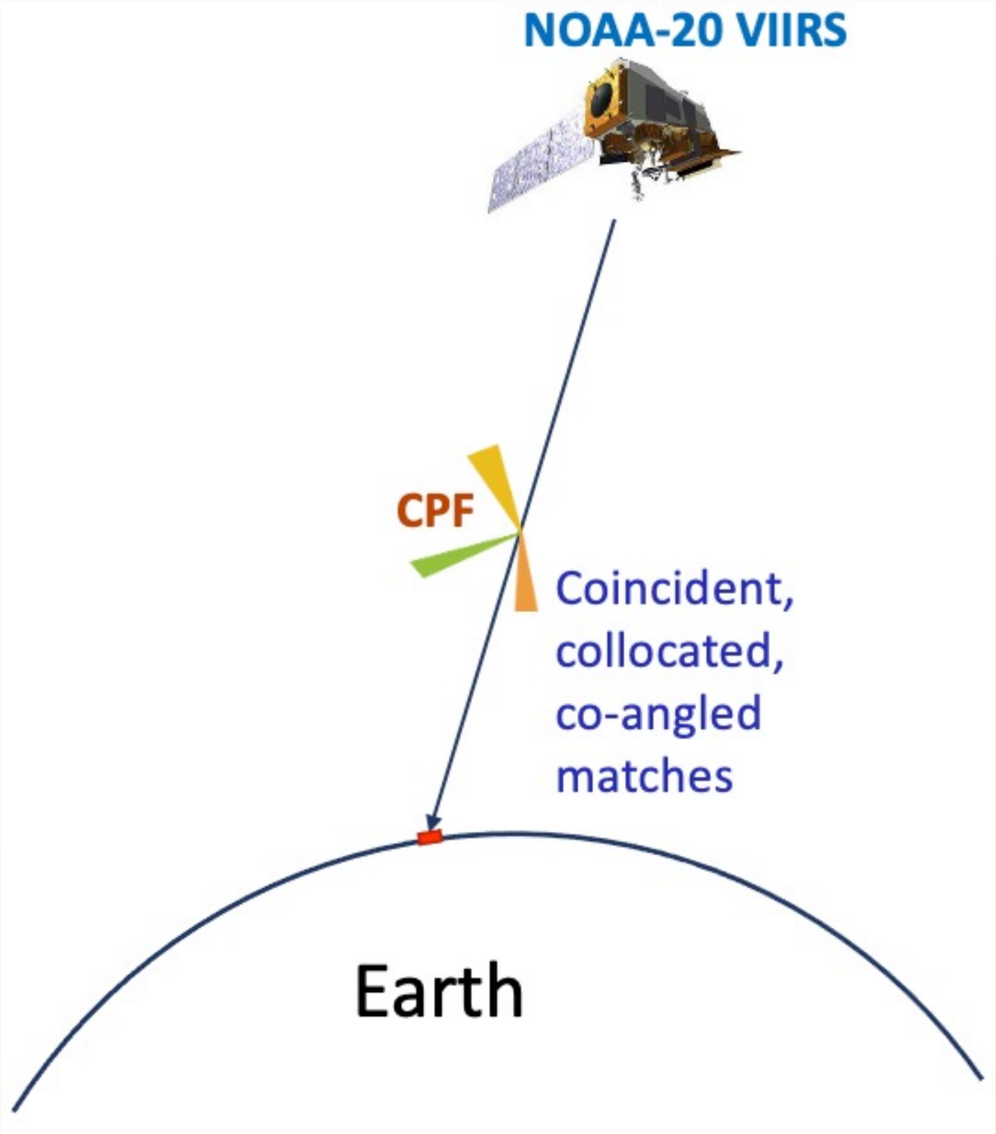
Demonstrate ability to transfer calibration to other key RS satellite sensors by inter-calibrating with CERES & VIIRS.

	Objective #1	**Objective #2**
Uncertainty	Spectrally-resolved & broadband reflectance: ≤0.3% (1σ)	Inter-calibration **methodology** uncertainty: ≤0.3% (1σ)
Data Product	Level 1A: Highest accuracy, best for inter-cal, lunar obs Level 1B: Approx. consistent spectral & spatial sampling, best for science studies using nadir spectra	Level 4: One each for CPF-VIIRS & CPF-CERES inter-cal. Merged data products including all required info for inter-cal analysis

https://clarreo-pathfinder.larc.nasa.gov/

Intercalibration between CPF and Target Instrument

- An idealized intercalibration setup requires perfectly matched data in **time**, **space**, **angles**, and **wavelengths**
- Realistic intercalibration tolerates finite differences in sampling, thereby resulting in several sources of uncertainty
  - *Spatial mismatch*
  - *Angular differences (SZA, VZA, and RAA)*
  - *Spectral band differences*
- CPF will demonstrate a state-of-the-art intercalibration methodology mitigating the uncertainties from imperfect data matching
  - *2-axis pointing capability*
  - *Mitigates impacts from spatial, angular, and spectral mismatches*



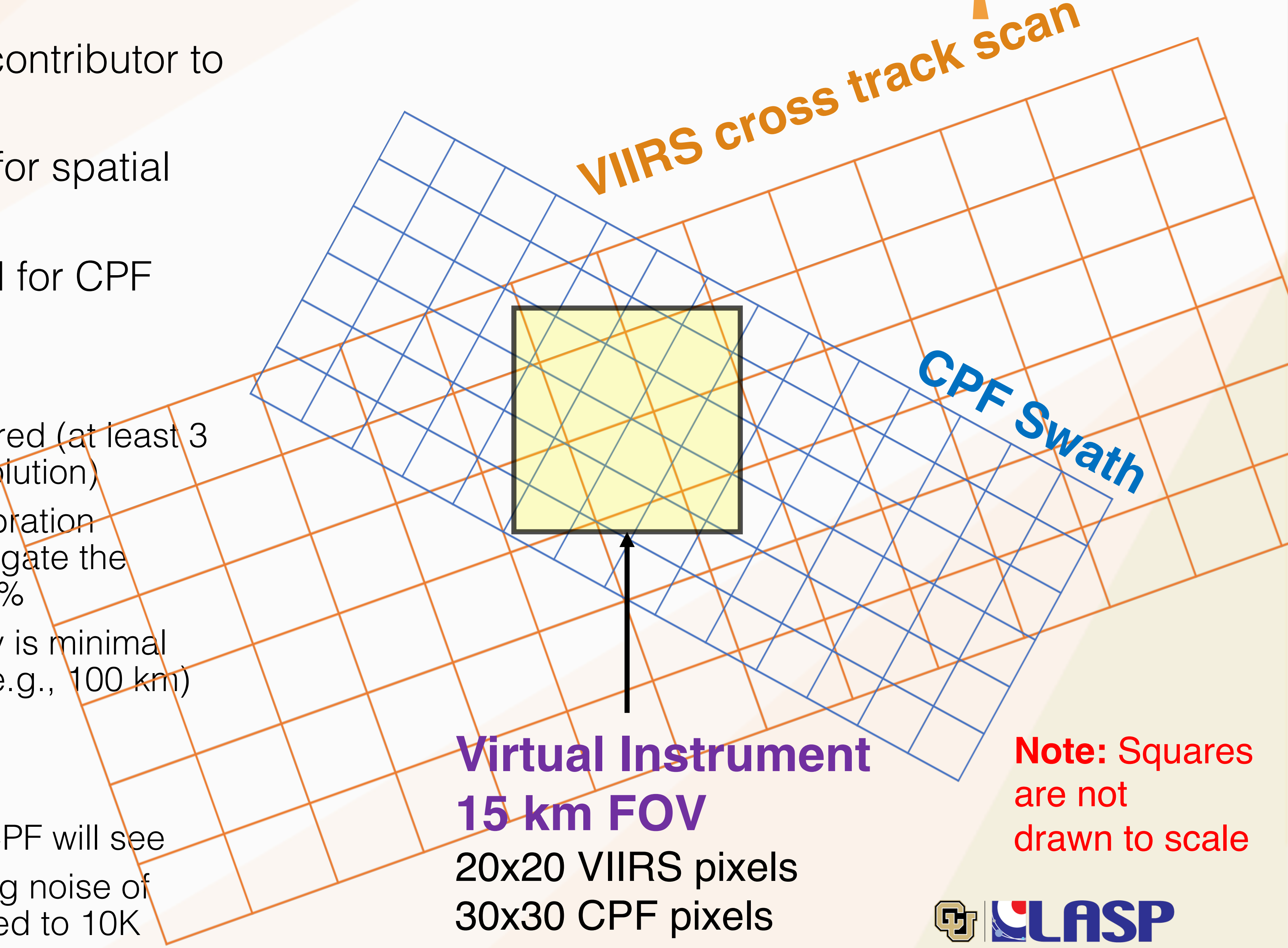
CPF-Target (CERES or VIIRS) Intercalibration Uncertainty Budget

CPF-Target Intercalibration Uncertainty Sources

- **Spatial Matching Noise (<0.1%)**
  Spatial convolution of CPF spectra and target instrument measurements within intercalibration footprints
- **Point Spread Function Knowledge Uncertainty (<0.1%)**
  Applicable to CERES only
- **Spectral Matching (<0.1%)**
  Difference in spectral coverage between CPF and target instrument
- **Angular Adjustment (<0.1%)**
  Imperfect angles matching between CPF and target instrument
- **Unaccounted uncertainty (<0.1%)**
  Uncertainty Contribution due to any instability in the target instrument within a month

Temporal and Spatial matching noise

- Spatial mismatching is a prime contributor to uncertainty budget
- For VIIRS, 15 km (at nadir) FOV for spatial convolution
- For CERES, prelaunch PSF used for CPF spatial convolution
- Based on Wielicki et al. (2008)
  - Large intercalibration FOV preferred (at least 3 to 10 times the native spatial resolution)
  - For ≥15 km FOV, ~5000 intercalibration samples would be needed to mitigate the spatial matching noise below 0.1%
  - Dependence on time simultaneity is minimal below 6 minutes for larger FOV (e.g., 100 km)
  - Summarized in CPF-SER-022
- Revisiting the sampling study
  - Emulating scene variability that CPF will see
  - Estimated single sample matching noise of 10% -> Increases samples needed to 10K



Note: Squares are not drawn to scale

Can we expect >10,000 samples monthly?

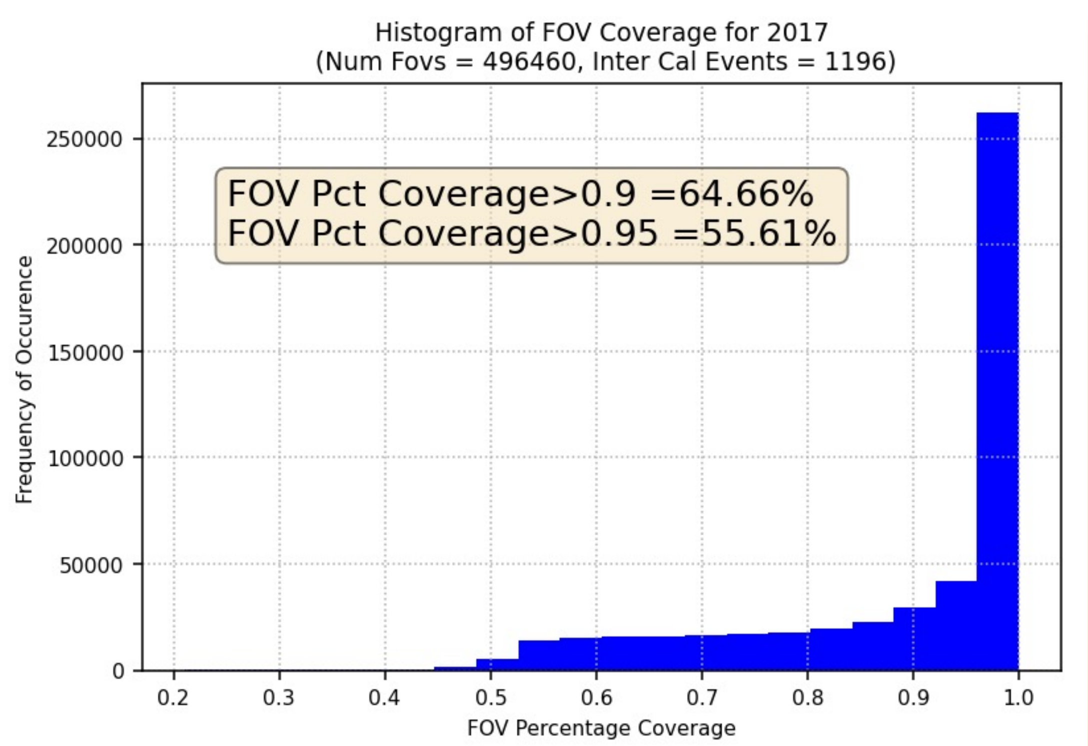
CLARREO Pathfinder

Intercalibration Sampling Estimates

- Intercalibration Sample Criteria Reduce number of samples included in monthly reference-target comparison
  - At least 95% coverage of CPF & Target footprints
  - Sun-view geometry limits (SZA, RAZ)
  - Low probability of sun glint
  - VIIRS only (low polarization scenes)
- 10% Reduction due to ISS maneuvers prohibiting Earth View during IC events

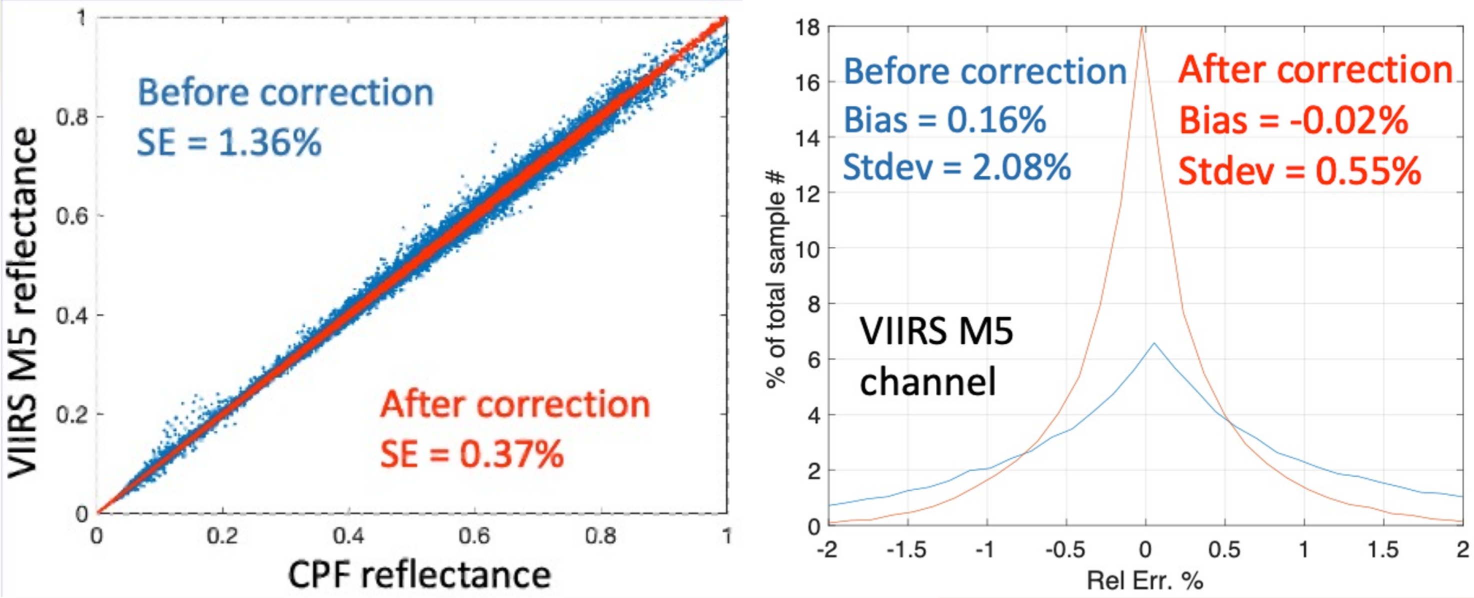
CPF-CERES estimate: ~12K/month

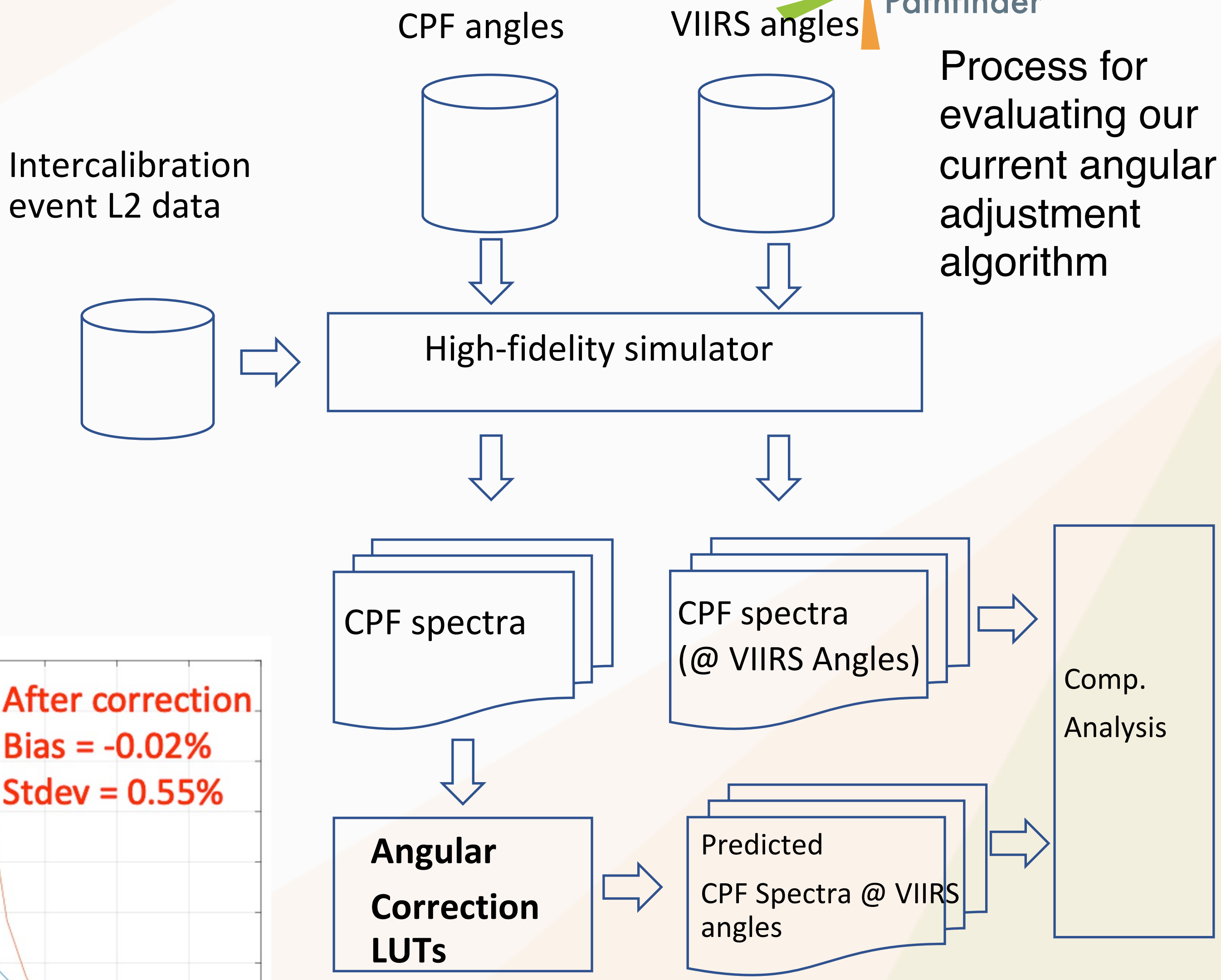
2017 Low-Fidelity Intercal Simulation Data – Est. CPF-CERES Sampling



CPF-CERES Angular Adjustment

- CPF IC team has developed a PCRTM-based algorithm for angular adjustment
- Angular correction LUTs generated based on thousands of simulated CPF-like radiance spectra (randomly chosen) at different angular conditions
- Significant reduction of bias and noise after angular correction



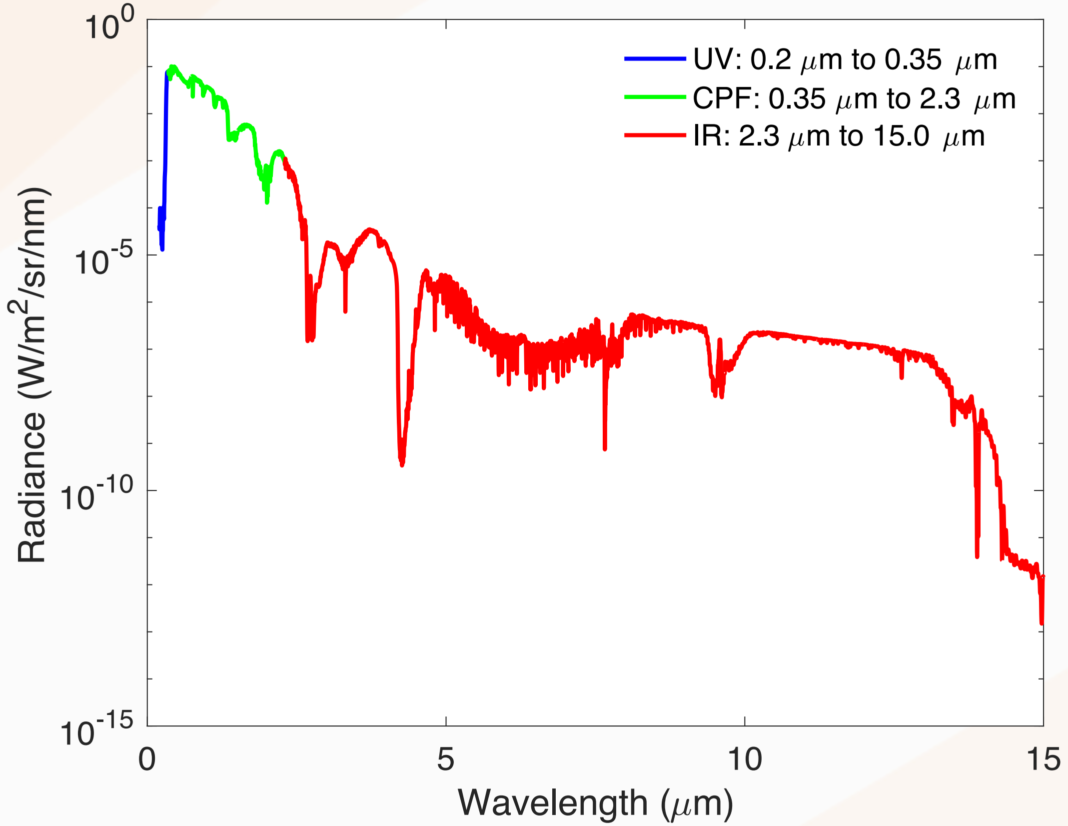


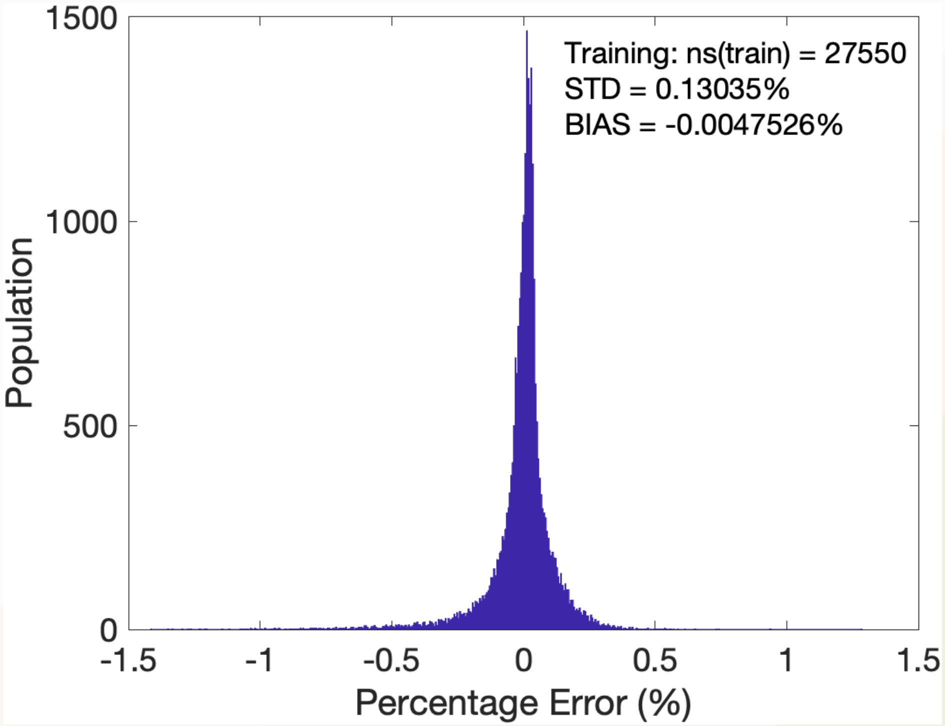
Process for evaluating our current angular adjustment algorithm

Algorithm Development: *Wan Wu & Xu Liu*

Spectral range extension for CPF-CERES intercalibration

- CPF spectral range (350-2300 nm)
- CPF measurements must be extended to **200 nm – 5 µm** to account for CERES unfiltered radiance definition
- PCRTM-based spectral gap filling algorithm
- Anticipated **1-σ uncertainty < 0.1%**

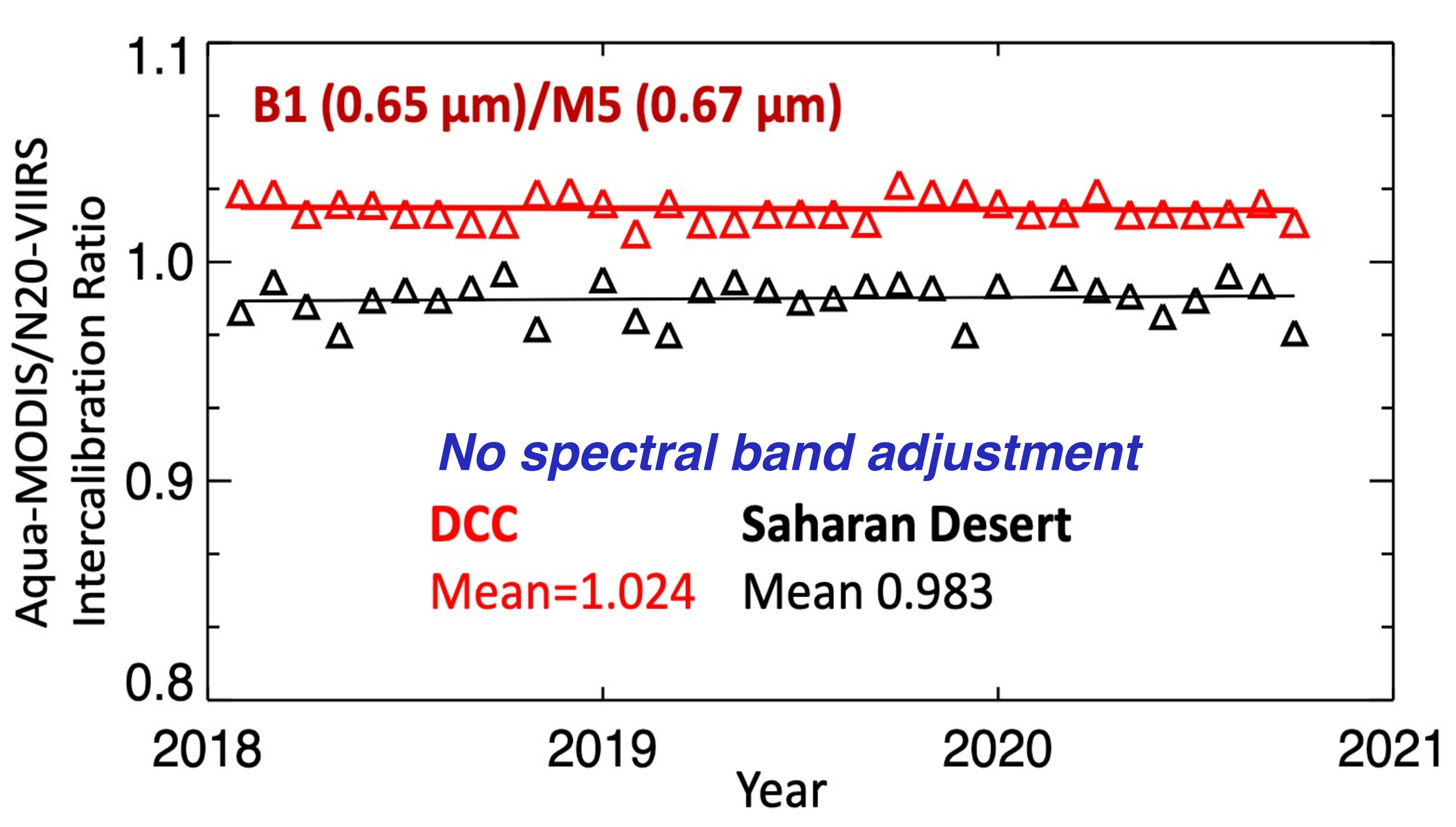


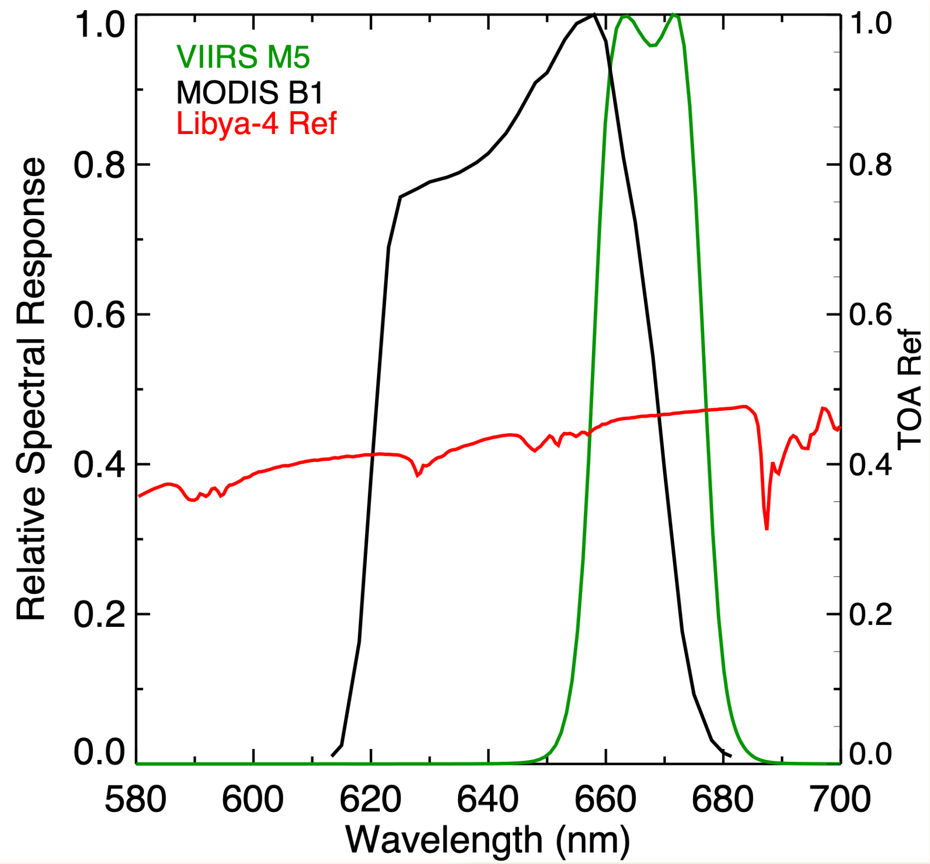


1-σ uncertainty = $STD/\sqrt{N}$

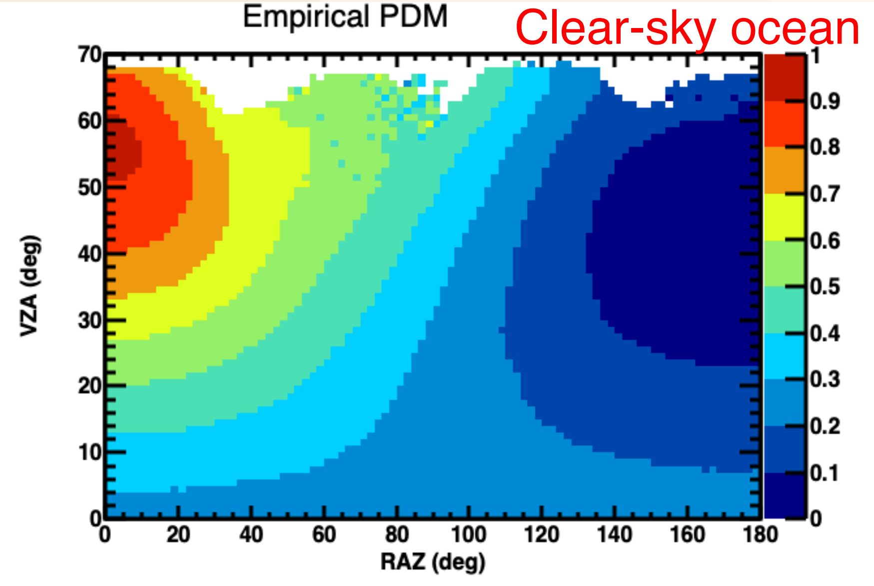
Spectral wavelength matching

- Spectral mismatch between reference and target sensors results in scene-dependent intercalibration results (e.g., MODIS and VIIRS)
- Hyperspectral measurements from reference sensor substantially mitigates the spectral difference issue
- At 4 nm spectral sampling, the impact is within 0.1% for MODIS bands (Wu et. al. 2015)



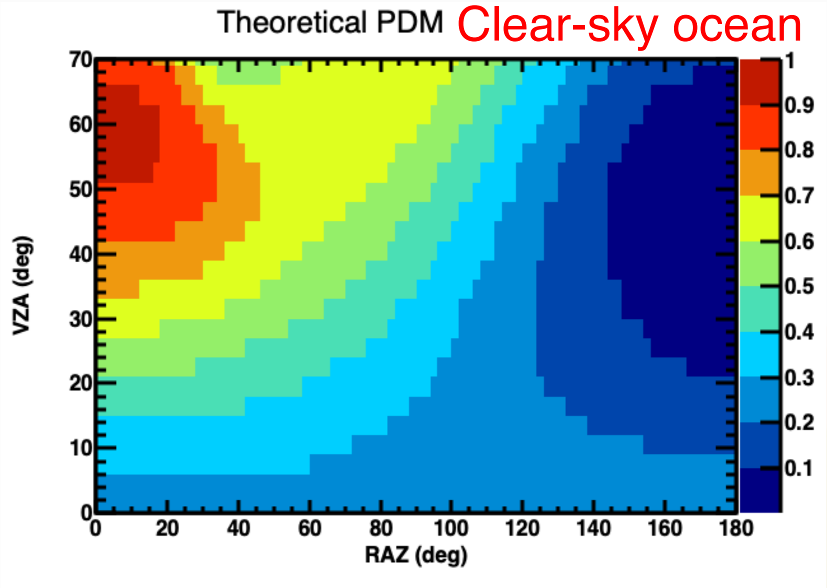


Polarization Distribution Model (PDM) Look-up Tables



PDM Application Module: Using VIIRS scene characterization info from L2 files, identifies correct LUT DOP/AOLP estimates from ePDMs & tPDMs

PDMs will be used to identify low-polarized radiances.



Empirical PDM Conditions: Constructed from PARASOL/POLDER Data
- SZA = [40º,50º]
- Band = 670 nm
- AOD = [0.05, 0.1]
- Wind Sp. = [2 m/s,10 m/s]

Developed by: *Daniel Goldin & Costy Lukashin*

Development Lead: *Daniel Goldin*

ePDM
- Based on Polder measurements
- 3 wavelengths: 490, 670, and 865 nm
- Wavelength interpolation

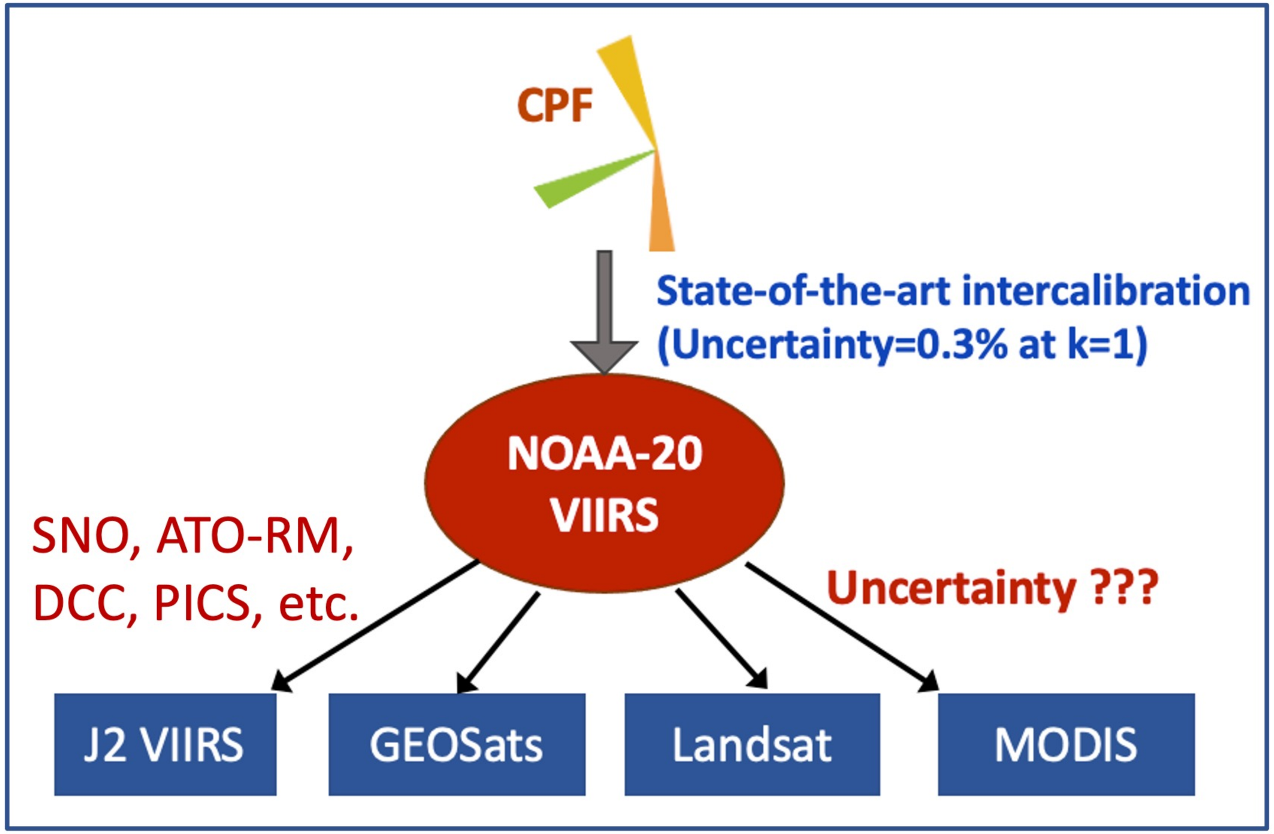
tPDM
- ADRTM simulation
- All wavelengths

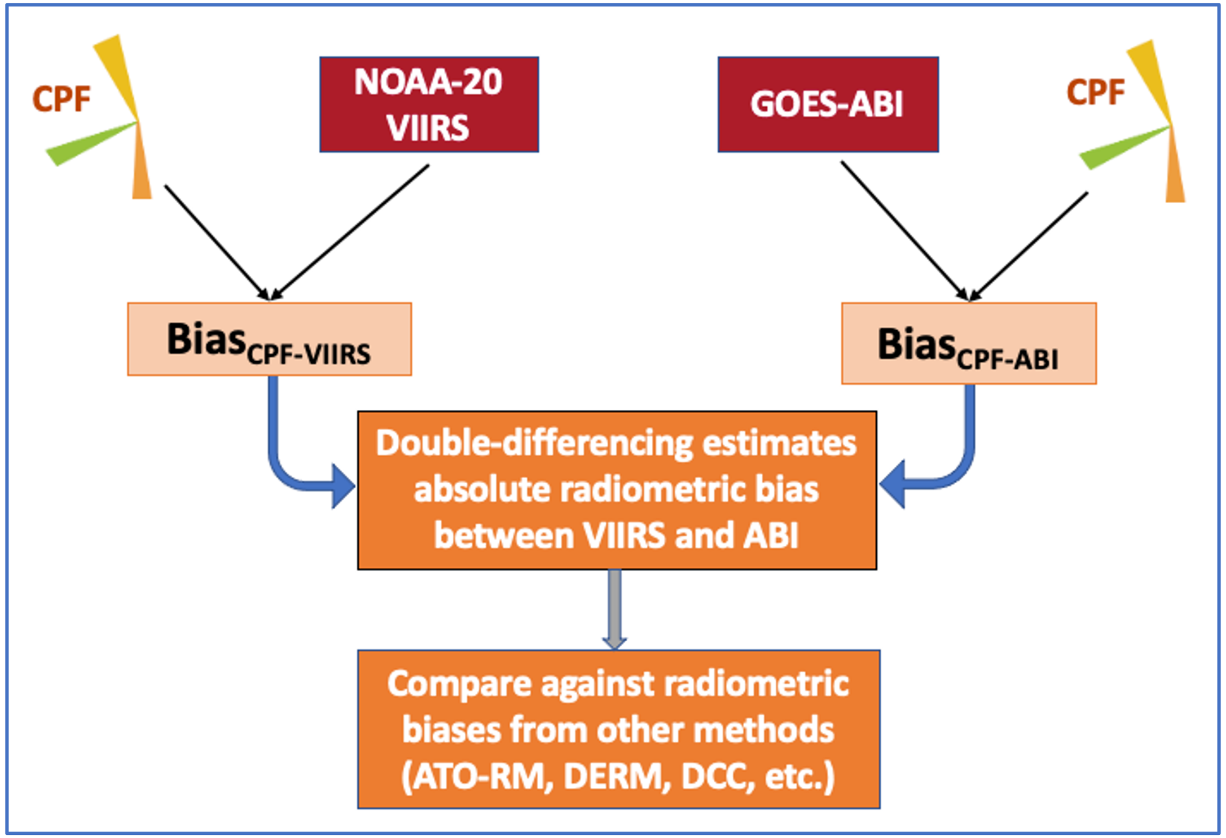
Theoretical PDMs: Simulated using Adding-Doubling Radiative Transfer Model
- SZA = 45º
- Band = 672 nm
- AOD = 0.076
- Wind Sp. = 7.5 m/s

Simulated by: *Wenbo Sun*

CPF Intercalibration Benefits

- Improved reference instrument for satellite intercalibration
- Lunar reflectance characterization
- PICS characterization at hyperspectral level
- Augmenting existing intercalibration approaches





CPF Timeframe Update

- CPF launch delayed (previous launch date was Dec 2023)
- Payload delivery date: No earlier than Spring 2024
- ISS Schedule : Launch no earlier than late 2025 (TBR)

Conclusions

- CPF will demonstrate a state-of-the-art intercalibration capability (0.3% uncertainty at k=1) by calibrating CERES and VIIRS against high-accuracy CPF measurements
  - Extensive # of intercalibration footprints
  - CPF pointing capability
  - PDMs
  - PCRTM-based angular adjustments and spectral corrections

- Scheduled nadir scans of CPF can be used to intercalibrate other RS imagers in GEO and LEO orbits
- CPF measurements will assist validating other intercalibration methodologies and enhance the radiometric and spectral characterization of invariant Earth targets (DCC, PICS, etc.)